

Quantitative X-ray imaging of magnetic vortices in permalloy disks

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The static and dynamic properties of magnetic vortices which occur in sub-micron sized elements are attracting increased interest both for fundamental and applied reasons [1-8]. The vortex structure in a thin disk is characterized by a curling magnetization in the plane of the disk and a vortex core in the center, where the magnetization points perpendicular to the plane. To investigate and understand the topology and the fast spin dynamics of magnetic vortex structures, advanced analytical microscopic tools with high spatial and temporal resolution in combination with fully 3D micromagnetic simulations are required.

We have carried out a detailed study of the static character of magnetic vortices in sub-micron sized permalloy (Py: Fe₂₀Ni₈₀) disks with thicknesses between 50 and 150 nm by high resolution magnetic transmission soft X-ray microscopy [9]. The experiments have been performed at the full field soft X-ray microscope XM-1 at the Advanced Light Source in Berkeley CA, where Fresnel zone plates provide a better than 25 nm spatial resolution. Since the XMCD contrast scales with the projection of the magnetic moments onto the photon propagation direction, we are able to image in perpendicular geometry directly the magnetic vortex core, which shows up as dark or white contrast depending whether the core magnetization points in or out of the disk plane (Fig.1). We observe a decrease of the vortex core radius (HWHM) from 24.8 to 13.5 nm with decreasing disk thickness from 150 to 50 nm, resp.(Fig 2). 3D micromagnetic simulations, which show the well-known "barrel" structure, confirm that the experimental radii of the vortex cores are in very good agreement with those determined from the thickness averaged magnetization profiles for our geometries (Fig 3). This proves both the validity of the micromagnetic simulation to describe the vortex core and the spatial resolution obtained with the X-ray microscope. Our results also show that with state-of-the-art X-ray optics magnetic vortices and domain walls can be well resolved, in nanosized elements down to about 50 nm thickness. Improvements in spatial resolution with future X-ray optics should lower these limits significantly.

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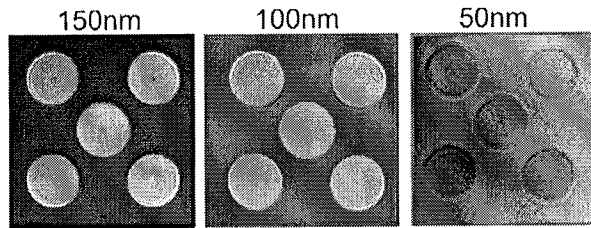


Fig 1: X-ray microscopy images of 500 nm diameter PY disks of thicknesses between 50-150 nm. The dark/white spots in the center are the magnetic vortex cores pointing in/out of the plane of the disk.

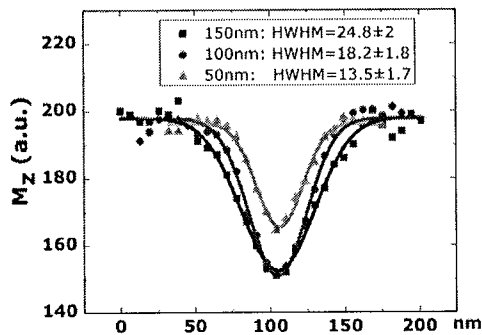


Fig. 2 Vortex core profiles derived from the X-ray images.

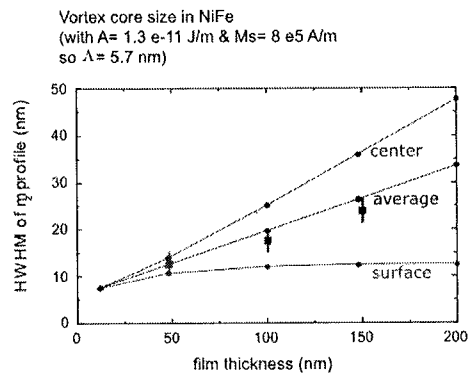


Fig. 3 3D micromagnetic simulations of the HWHM m_z profile taking into account the barrel structure. The experimental data points fit well to the thickness averaged profiles,